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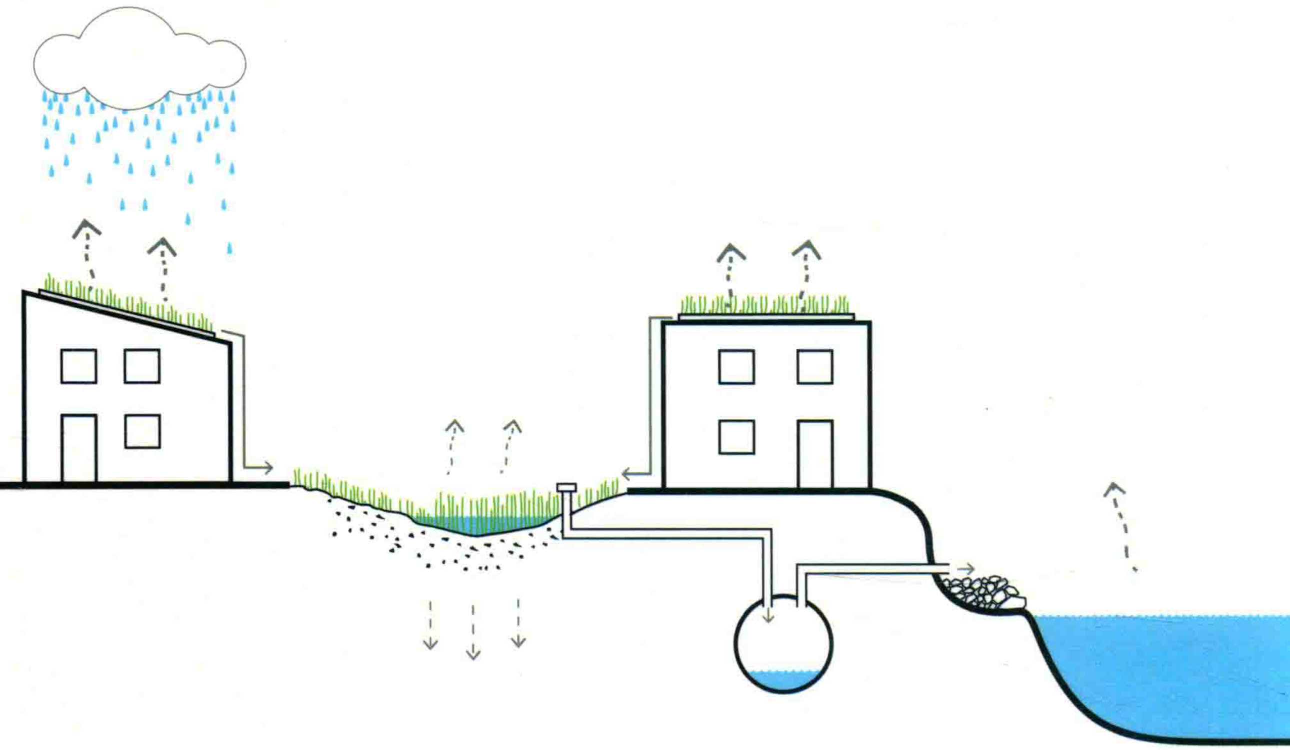

Living Roofs in Integrated Urban Water Systems

ROUTLEDGE

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With the infrastructure to manage stormwater threats in cities becoming increasingly expensive to build or repair, the design community needs to look at alternative approaches. Living roofs present an opportunity to complement ground-level stormwater control measures, contributing to a holistic, integrated urban water management system.

This book offers tools to plan and design living roofs, in the context of effectively mitigating stormwater. Quantitative tools for engineering calculations and qualitative discussion of potential influences and interactions of the design team and assembly elements are addressed.

Daniel Roehr is an Associate Professor at the University of British Columbia School of Architecture and Landscape Architecture in Vancouver, Canada, a registered landscape architect in Vancouver and Berlin and a horticulturalist. Roehr has designed and researched living roofs for over 20 years with his most significant work being the ground-breaking water sensitive living roof design of the DaimlerChrysler project Potsdamer Platz in Berlin, Germany.

Elizabeth Fassman-Beck is an Associate Professor in the Department of Civil, Environmental, and Ocean Engineering at Stevens Institute of Technology in Hoboken, New Jersey, USA. She has worked extensively with regulatory agencies to develop evidence-based technical and practical design criteria for stormwater control measures. Her former research team in Auckland, New Zealand developed the first living roof design guidance prioritizing stormwater management.

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Contributors

Audrey Bild, *Research and Editing*. Bild is an intern architect in Vancouver, Canada. Inspired by her graduate work at the University of British Columbia, School of Landscape Architecture and Landscape Architecture, she continues to pursue her passion for sustainability and particular interest in water systems as they relate to the field of architectural design through research. In the future, she aspires to lead a career that focuses on integrated landscape and architectural design practices.

Elizabeth Fassman-Beck, Ph.D. Fassman-Beck is an Associate Professor in the Department of Civil, Environmental, and Ocean Engineering at Stevens Institute of Technology in Hoboken, New Jersey, USA. Elizabeth received a B.S.E. in Civil and Environmental Engineering from Duke University (North Carolina, USA). She earned an M.S. and Ph.D. from the University of Virginia (USA) through research on the hydrology and water quality treatment of urban stormwater best management practices. Elizabeth spent nearly ten years as an academic at the University of Auckland (New Zealand), performing engineering research and teaching design in low impact development and green infrastructure for stormwater management. She has worked extensively with regulatory authorities to develop evidence-based technical and practical design criteria for stormwater control measures. Through collaboration since 2005, Fassman-Beck and Dr. Robyn Simcock were responsible for creating living roof design standards for Auckland, derived from in-depth research and practical applications. Fassman-Beck and Simcock were awarded the American Society of Civil Engineers Wesley W. Horner Award in 2014 for their research in living roof design. Elizabeth is actively engaged with professional practice and international research, serving on the IWA-IAHR Joint Committee on Urban Drainage and the EWRI Urban Water Resources Research Council, where she chairs the Green Roofs Task Committee. Across New Zealand and the USA, she conducts research-informed professional development courses for industry.

Kevin (Yuewei) Kong, *Graphics*. Kong obtained his B. Arch degree at South China University of Technology (SCUT) in Guangzhou, P.R. China in 2004, and is a graduate of the University of British Columbia Master of Advanced Studies in

Landscape Architecture (MASLA) program. Kong's MASLA thesis focused on developing a methodology to quantify the potential of living roofs to reduce stormwater runoff in different locations with disparate climatic conditions, using local climatic data, the properties of soil materials and plants. Kong currently practices architecture in Vancouver, Canada, and continues his research on rainwater harvesting and stormwater management in the urban environment at the UBC's Greenskins Lab.

Daniel Roehr, MBCSLA, CSLA, AKB. Roehr is an Associate Professor at the University of British Columbia School of Architecture and Landscape Architecture in Vancouver, Canada. He is a registered landscape architect in Vancouver and Berlin as well as a horticulturalist. Daniel has earned a Higher National Diploma (HND) in Horticulture and Landscape Technology from Askham Bryan College (York, England) and a BA (hons) in Landscape Architecture from Heriot-Watt University (Edinburgh, Scotland). Roehr has designed and researched living roofs for over twenty years. With design projects spanning multiple scales in Europe, China and North America, his most significant work is the groundbreaking water sensitive living roof design of the DaimlerChrysler project Potsdamer Platz in Berlin, Germany. In 2007, he founded the research group Greenskins Lab at UBC. Roehr's current research focuses on the integration of living roofs as part of low impact development strategies for stormwater management. He regularly publishes and presents his findings at university lectures and conferences.

Robyn Simcock, Ph.D., *Contributing Author (Chp 3 & 4).* Simcock is an ecologist and soil scientist, works with storm water engineers to develop novel growth media and plant systems using natural ecosystem processes to mitigate impacts of highly modified urban environments. Robyn is a graduate in Horticultural Science (BHortSci First Class; Massey University, New Zealand) with a Ph.D. in mine restoration. She has worked for Landcare Research, the crown-owned research institute charged with driving innovation to protect and enhance New Zealand's terrestrial environment, for nearly 20 years. Since 2006 Robyn has worked collaboratively with regulatory authorities to deliver research and technical guidance (with Dr. Elizabeth Fassman-Beck) on living roofs and Green Infrastructure, including New Zealand's unique biota and rich volcano-generated resources.

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Daniel extends his fondest gratitude to his parents, who have always supported his career, despite years abroad for the greater part of his life.

Elizabeth would humbly like to thank her family for supporting and encouraging her research career from across the world, and seeing her through the writing of this book. She is especially grateful to her husband, Li San Beck, for his patience, and her mother, Kathleen Fassman, for inspiring her to research living roofs in the first place.

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Abbreviations

INSTITUTIONS

ASCE	American Society of Civil Engineers
ASTM	American Society of Testing Materials
EPA	(USA) Environmental Protection Agency
FLL	Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau
FSC	Forest Stewardship Council
LEED	Leadership in Energy and Environmental Design

TERMS

ARI	Annual Recurrence Interval
BMP	Best Management Practice
CAM	Crassulacean Acid Metabolism
CN	Curve Number
CSO	Combined Sewer Overflow
ESD	Environmental Site Design
ET	Evapotranspiration
GI	Green Infrastructure
GSI	Green Stormwater Infrastructure
LID	Low Impact Development
LWA	Light-Weight Aggregate
PAW	Plant Available Water
SBS	Styrene Butadiene Styrene
SCM	Stormwater Control Measure
SMEF	Soil Moisture Extraction Function
SUDS	Sustainable Urban Drainage System
TSS	Total Suspended Solids
WSUD	Water Sensitive Urban Design

Contents

Chapter 1: Introduction

1.1 WHY WORRY ABOUT WATER? WATER AS A DRIVER FOR LIVING ROOF IMPLEMENTATION

Water is crucial for life on earth. It is our most precious resource. In many parts of the world, water scarcity causes immense hardship for human, animal and plant life. The extent of these areas is steadily increasing (International Water Management Institute 2000; Rijsberman 2005; UN Water, Food and Agriculture Organization of the United Nations 2007). The quality of water has been degrading rapidly since the Industrial Revolution, a situation which has been accelerated by the immense increase in population over the last 40 years (Albiac 2009; Carr and Neary 2009; Nienhuis and Leuven 2001). In the Western world, concerns over water extend beyond basic infrastructure to now address the preservation of ecosystems and ecosystem services. With increasing urgency, urban development professionals including architects, landscape architects, engineers and planners are researching and implementing various methods to recycle, store and reuse water, improve its quality, and protect or restore the natural resource base from which it is extracted (Margulis and Chaouni 2011; Planning Institute Australia 2003).

What we do with water use (how much) and its management (quality, where it ends up, and how fast it travels) at a local level always impacts a larger system, which in turn, feeds back to the availability and quality of water in our cities. Of the many forms that water takes, this book is concerned with urban stormwater runoff. It examines the role and design of living roofs to mitigate runoff's environmental and infrastructure impacts, while creating productive urban spaces. Living roofs have to be seen from two sides: the pragmatic/technical side from an engineer's point of view alongside the environmental, social and/or aesthetic/experiential side from a designer's point of view. Designers try to create a human experience resulting in a higher quality of life but this cannot happen without the engineer's objective to protect water resources for creating and sustaining life.

Urban stormwater runoff poses a suite of receiving water and infrastructure impacts that threaten public health and welfare as much as ecosystem services, but also offers an opportunity of a resource to be captured for beneficial uses.

The historic focus of an urban drainage system was to expediently remove or dispose of runoff so as not to disrupt urban activities, damage structures or threaten public safety. Expedient removal is no longer the only goal or cost. In some cases, it is not the goal at all. Almost every aspect of the hydrologic cycle (water's distribution and flux in a watershed) is modified by urban development. In a natural forested condition, 10–20 mm of precipitation may be intercepted by the vegetated canopy and infiltrated (soaked) into the ground before stormwater runoff is generated at the surface. In an urbanized condition, runoff may be generated from as little as 2 mm of rain. Thus, in urban settings, flows are generated almost every time it rains, and pollutants are transported to receiving waters such as streams, rivers, lakes, estuaries, bays and harbors. Increased flow rates, runoff volumes and occurrence of runoff along with how quickly runoff is initiated contribute to channel erosion and instability, which degrades both physical and biological habitat structure by a process known as hydromodification (US EPA 1993). Studies show that marked alteration of channel flow processes is associated with declining ecological health, or degradation of the physical channel attributes required for normal ecological functioning (Gippel 2001). Across the United States, receiving water quality has largely been considered "degraded" for decades; pollutants carried by urban runoff are largely discharged without treatment. Altogether, hydromodification and pollutant loadings compromise aquatic habitat, infrastructure and property almost every time it rains.

Reducing or avoiding impacts from "everyday" rainfall events is increasingly incorporated into policy, but has not historically been the focus. Since 2001, US state and municipal agencies in Portland, Philadelphia, Seattle, Atlanta, Chicago, New York, Pittsburgh, Washington State, California, Maryland, Vermont and Virginia have introduced policies and related design requirements. Significant legislation enacted in 2007, Section 438 of the USA Energy Independence and Security Act, requires extensive on-site runoff control from "everyday" events for federal facilities undergoing new or redevelopment. Living roof technology is perfectly suited to mitigate these sorts of storm events.

In many older cities, "everyday" stormwater impacts to receiving environments are exacerbated or even superseded by combined sewer overflows (CSOs). Combined sewers are intended to carry sanitary sewerage and stormwater runoff through the same pipes to a municipal wastewater treatment plant. In many major cities around the world, urban infill and densification now generate flows well exceeding the carrying capacity of the combined sewer network. By design, overflow points discharge untreated runoff and sanitary sewerage into receiving environments when the capacity of the sewer is exceeded during wet weather (e.g., rain or snowmelt). While the intention is to prevent overloading the municipal wastewater treatment facility, and causing even greater volumes of untreated wastewater discharge, the impacts to local receiving environments can be devastating. In Brooklyn, NY, modeling predicts CSO events to occur almost every time it rains, without intervention (City of New York 2008). In New Jersey, the state with the highest population density in the United States, as little as 5 mm of rain regularly causes CSOs (NY/NJ Baykeeper.org 2013). Philadelphia is served by 164 permitted CSO discharge points, serving 48 percent of the city (PWD 2011). While larger storms cause the greatest volume of CSO, smaller storms create the greatest number of CSO events. In many areas of the United States, these sorts of discharges are in violation of the 1972 Clean Water Act and its amendments (including the 1994 Combined Sewer Overflow Control Policy) and/or the Wet Weather Water Quality Act of 2000. In the Pacific Northwest, CSOs and runoff contaminants including the elevated temperature of untreated stormwater runoff threaten salmonids protected by the 1973 Endangered Species Act. Environmental regulation and impending lawsuits and/or fines, exacerbated by shifting public awareness and opinion, is causing municipalities and water utilities to invest significant resources in reducing the frequency and volume of CSOs, and restoring degraded waterways.

Upgrading buried infrastructure is increasingly found to be uneconomical and impractical compared to surface-level action. Rigid grey infrastructure (pipes, pumps, tanks and centralized treatment plants) lacks resilience. Alternatively, small and large cities around the world are developing or are already implementing green infrastructure (GI) solutions for stormwater management. Although many definitions of GI have been proposed, a useful compilation is "Natural and engineered ecological systems which integrate with the built environment to provide the widest range of ecological, community, and infrastructure services" (greeningofcities.org 2012). The term green stormwater infrastructure (GSI) is specifically used to identify approaches for runoff management.

Decisions defending GI and GSI adoption cite economics, inability to achieve technical objectives using grey infrastructure, and multi-functionality over and above provision of ecosystem services, particularly with respect to human health and social capital. Across the world, the two largest municipal investments in GSI were recently introduced in Philadelphia and New York City, specifically to address CSO control and receiving water quality improvement. After a comprehensive alternatives analysis, the Philadelphia Water Department (PWD) determined that traditional grey infrastructure would be "cost prohibitive while also missing the restoration mark." Instead, the PWD is investing US$1.2 billion (2009 net present value) in GSI and in excess of US$3 billion in GI over 25 years "towards greening the city as a means to provide specific benefits ... while meeting ecological restoration goals" (PWD 2011: 3). Implementing GI across New York City is projected to eliminate $1.4 billion and defer $2 billion from the municipal government's budget for state-mandated grey infrastructure projects (City of New York 2012).

On a smaller scale, site or block-level initiatives are often instigated by municipalities in response to neighborhood complaints. Many successful stories and/or pilot projects are emerging from Seattle, Portland, Lancaster (Pennsylvania), New York City and Washington, DC where GI solutions for stormwater are integrated into street or intersection redevelopment to improve traffic and pedestrian safety. Addressing runoff problems at – or close to – the source with GI eases the